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Crop Rotation Experiments

IN THE OHIO VALLEY— 1937-1952

WEST VIRGINIA UNIVERSITY AGRICULTURAL EXPERIMENT STATION

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Crop Rotation Experiments in the Ohio Valley—1937-1952

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Summary and Conclusions

Results of 16 years' tests of different cropping systems at different lime and fertility levels are reported. The results are divided into two eight-year periods representing different basic fertilizer treatments. During the first period (1937-1944), the maximum fertilizer treatment was 250 pounds of a 4-10-6 fertilizer applied on the average of once each year. During the second period (1945-1952), the rate was unchanged but the analysis used for maximum treatment was a 5-10-10 or a 10-10-10 fertilizer.

The following general conclusions can be drawn from the data.

1. Crop yields increased as length of rotation increased up to three to four years.

2. Yields were increased by growing a legume and plowing under as green manure crop or as crop residues following its removal as hay.

3. Manure had a marked effect on yields of all crops, the effect decreasing as time after application increased.

4. The two-, three- or four-year rotations with manure applied before corn at the rate of 10 tons per acre produced over 90 bushels of corn per acre without additional fertilizer. Adding fertilizer at the rate of 250 pounds per acre increased yields to about 100 bushels per acre during the last eight-year period.

5. Liming to maintain soil pH at or near pH 6.5 gave higher yields than were secured on the unlimed plots. Much of the increase appeared to be related to better legume growth and consequently more available nitrogen for crops. However, even without legumes both corn and wheat yielded better on the limed than on the unlimed plots.

6. Response to nitrogen fertilizer varied with cropping system and treatment. Greatest response to nitrogen was noted when there were no legumes in the cropping system and when no manure was applied. Undoubtedly a considerable part of the effect of legumes and manure was the result of the nitrogen they furnished.

7. Responses to potassium fertilizer were greatest on the unmanured plots. Plant symptoms of potassium deficiency on corn were evident on some of the plots which had not received any potassium fertilizer since 1922.

8. The maximum rate of fertilization used was relatively low. It seems quite probable that higher rates of fertilization would be necessary, at least in certain rotations, to give maximum or even optimum yields.

Crop Rotation Experiments in the Ohio Valley—1937-1952

T. C. McIlvaine, G. G. Pohlman and D. R. Browning

Introduction

THE systematic rotation of crops has been recognized for centuries as a desirable practice in crop production. The benefits have been variously attributed to better control of weeds, insects, and diseases and to better utilization of plant nutrients. Crop rotation experiments were initiated at the Lakin Experiment Farm in 1923 at which time an area of approximately 10 acres classified as Wheeling fine sandy loam was laid out in plots. These were planted in oats in 1923 and wheat in 1924 to study soil uniformity. Although considerable variation was found it was concluded that, by proper use of replicates, valuable information on cropping systems could be secured. Various cropping systems were studied and the results for the first 12 years were reported.[1] These showed the value of manure, lime, green manuring, and cropping system in maintaining satisfactory yields.

Following the completion of the 12 years' results certain revision seemed desirable. Because of poor production of certain crops and changes in type of agriculture, certain changes were made in the cropping systems. Oats, which had given low yields, was discontinued and winter barley substituted as a small grain crop in several of the rotations. Wheat was substituted for soybeans in some rotations. In certain three-year rotations clover and timothy or lespedeza were planted in the small grain replacing cowpeas or soybeans. Manure was omitted from these rotations. The rate of application of manure was changed to a uniform rate of 10 tons per acre instead of the amount produced by feeding the crops in the rotation. Some of the cropping systems were abandoned and the plots treated uniformly. Other minor changes will be noted later. Although some of these changes may have had an influence on the results obtained, in general the original objectives were retained. These were:

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[1] T. C. McIlvaine, G. G. Pohlman, *Crop Rotation Experiments in the Ohio Valley* (1925-1936), W. Va. Agr. Exp. Sta. Bul. 306, 1942.

1. To compare different crop rotations, with particular reference to their value for specific West Virginia conditions.

2. To determine the effect of lime on different crops and in different rotations.

3. To compare rotations receiving manure to those receiving only the crop residues.

4. To compare the effect of different cover crops on certain rotations.

The general plot layout was the same as previously used.[2] Each crop in each rotation was grown in duplicate each year. The results for each period, therefore, represent the average of two yields for each crop each year.

During the earlier period of the experiment, evidence of nitrogen and potassium deficiency were noted on certain of the plots. These were related to both treatment and cropping systems. In order to study response of fertilizer elements each plot was divided into three sub plots. The kind of fertilizer and rate of application for each crop are given in the discussion of results.

Management for the various rotations was in keeping with general management practices used in the area. Crop varieties used included U. S. 13 hybrid corn, Thorne wheat, Kentucky No. 1 barley, Kingwa soybeans, Grimm alfalfa, and commercial strains of clover, timothy, and Korean lespedeza. The rates of seeding were similar to those used in the area and reported previously except that there were three stalks of corn per hill instead of two, with hills 39 inches apart in the row. Fertilizer was applied in the hill for corn, in the row for potatoes, and broadcast for other crops. In most rotations hay crops were not topdressed, but additional fertilizer to maintain an average of 250 pounds per acre was applied on the small grain preceding the hay, except in the rotations which received manure. Certain treatments which applied only to specific rotations or groups of rotations will be noted in the discussion of results.

Experimental Results 1937-1944

The yield of crops in the various rotations and with the various fertilizer treatments are given in Table A (Appendix).

In order to discuss the results the cropping systems are grouped on the basis of length of rotation, use of manure, and lime treatments.

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[2] *Ibid.*

FOUR-YEAR ROTATIONS WITHOUT MANURE

Two of the original three rotations in this group were continued unchanged except for the addition of fertilizer variables. These were rotation A—potatoes with rye and vetch cover crop, corn, wheat, and clover-timothy, and rotation C—corn, wheat, clover-timothy, and timothy. These were grown on limed and unlimed plots. The pH of the soil in 1941 on the unlimed areas ranged from 5.19 to 5.54, and on the limed areas between 6.04 and 6.48. Fertilizer treatments and yields of crops in these rotations are given in Figure 1.

Difference in rates of fertilizer application as well as in cropping systems make interpretation of results somewhat difficult. Potato yields in rotation A were generally low because of inadequate control of insects and diseases on these small plots. Corn yields were consistently higher in rotation A than in rotation C. These higher yields were probably due to some residual effect of the fertilizer applied to potatoes. Wheat and first-year clover and timothy yields were similar in the two rotations.

Liming increased yields of corn, wheat, and first-year clover and timothy in all cases. Much of the increase was probably the result of better legume growth which furnished more nitrogen. The decrease from liming on second-year hay reflects the disappearance of the red clover and a lesser amount of timothy and other plants on the limed area. The benefit from liming on potato yields appears to be directly related to the better growth of legumes and the nitrogen they supplied to the potato crop. When nitrogen was applied to potatoes the unlimed plots gave the highest yield.

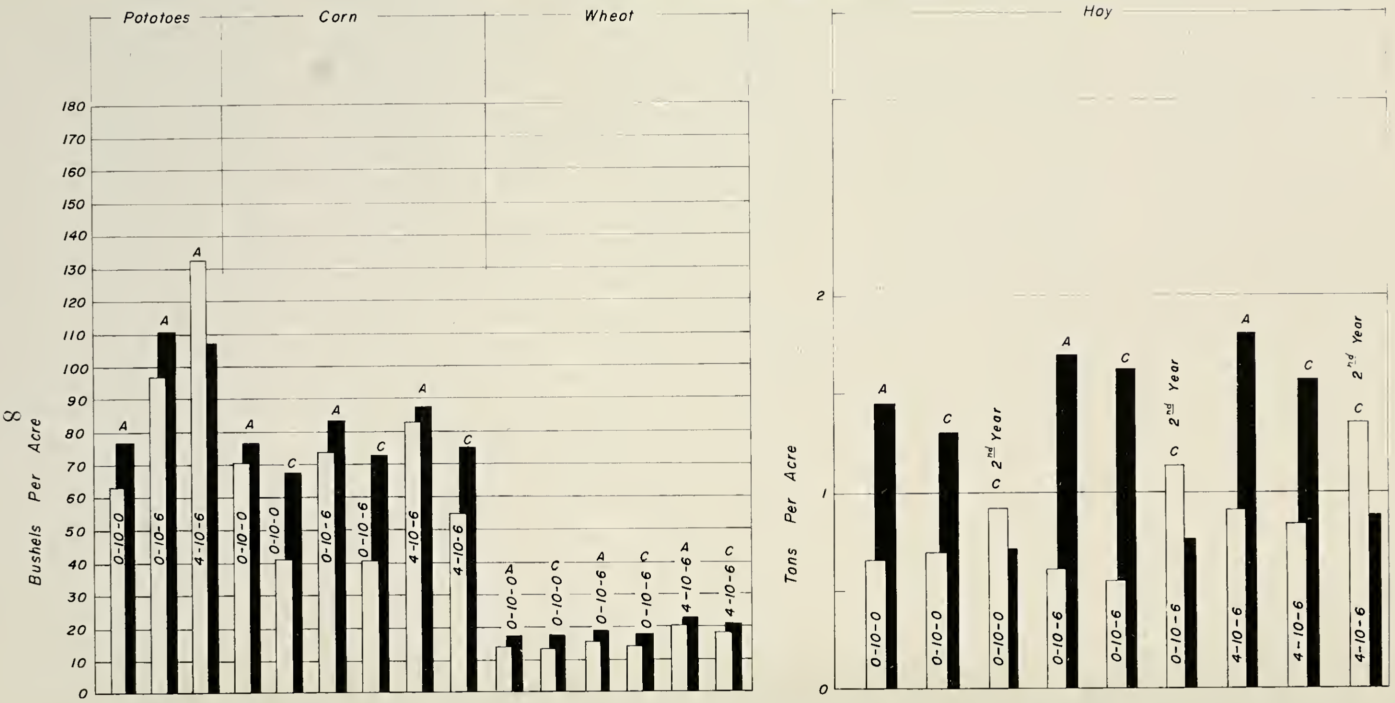
Potassium (0-10-6 vs. 0-10-0) had most effect on potatoes but also benefited the hay crop on the limed plots. Corn and wheat appeared to be only slightly affected by potassium.

Corn, wheat, and potato yields were increased by the application of nitrogen fertilizer (0-10-6 vs. 4-10-6). The nitrogen applied at wheat seeding time also seemed to benefit the yields of hay the first year on the unlimed plots. The small increase in second-year hay can be attributed to the nitrogen topdressing.

THREE-YEAR ROTATIONS

Three three-year rotations were compared with and without lime. These rotations had received applications of manure once in the rotation from 1925 to 1936. No manure was applied after 1936 and the cropping systems were changed to corn, barley, lespedeza (F); corn, barley, clover-timothy (G) ; and corn, wheat, clover and timothy (H). The yields of all crops are given in Figure 2.

FIGURE 1—Yield of crops in four-year rotations.

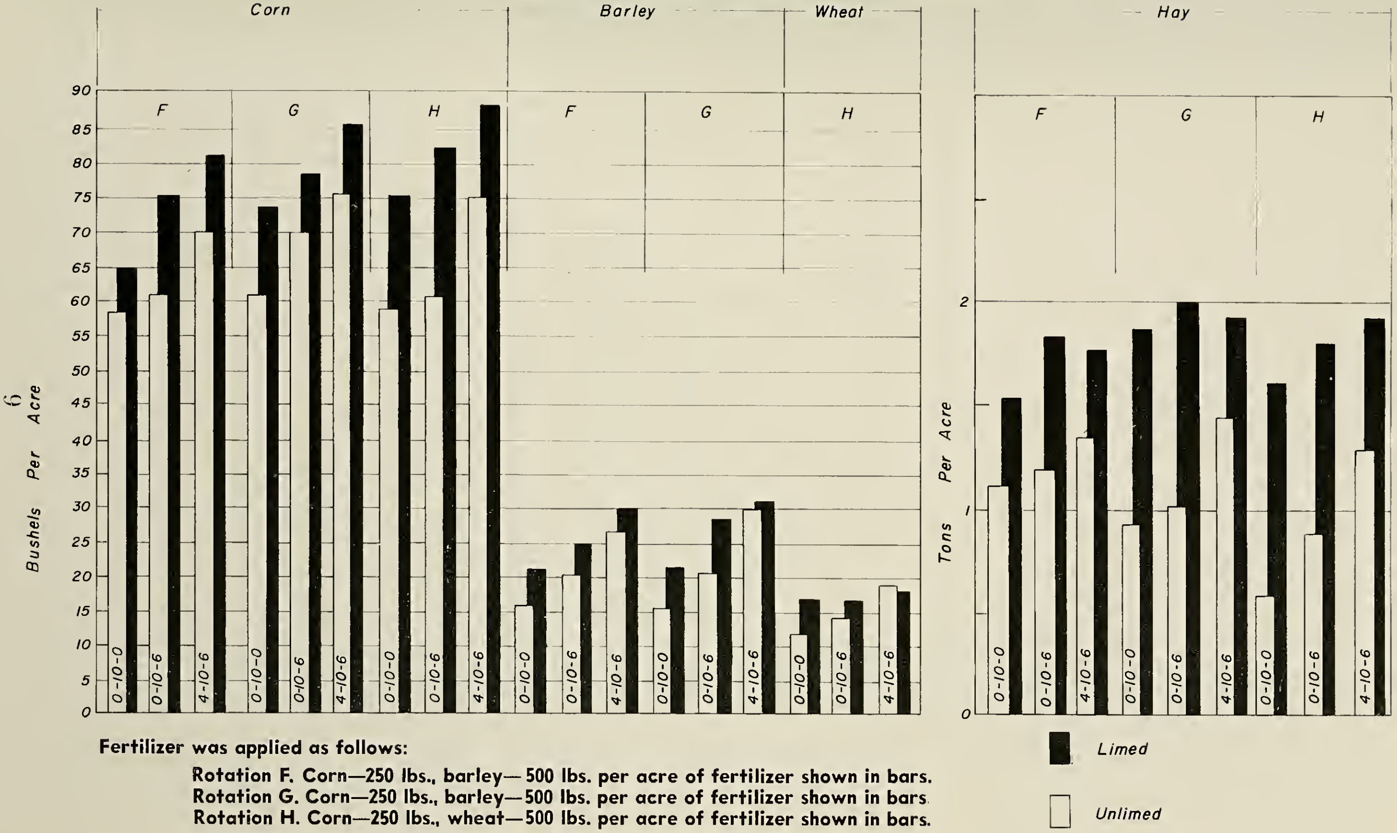


Fertilizer was applied as follows:

A. Potatoes—750 lbs., corn—250 lbs., wheat—500 lbs. per acre of fertilizer shown in bars. No fertilizer applied to clover and timothy.

B. Corn—250 lbs., wheat—500 lbs. per acre of fertilizer shown in bars. Timothy received nitrogen only at the rate of 10 pounds per acre on plot receiving 4-10-6 on corn and wheat. No fertilizer applied to clover and timothy.

FIGURE 2—Yield of crops in three-year rotations.



Fertilizer was applied as follows:

Rotation F. Corn—250 lbs., barley—500 lbs. per acre of fertilizer shown in bars.
Rotation G. Corn—250 lbs., barley—500 lbs. per acre of fertilizer shown in bars.
Rotation H. Corn—250 lbs., wheat—500 lbs. per acre of fertilizer shown in bars.

Corn yields were variable with little evident effect from cropping systems except that yields were usually somewhat lower following lespedeza (rotation F) than following clover and timothy. Liming increased corn yields in all rotations. Some increase resulted from the application of potash and nitrogen.

Barley yields were consistently higher on the limed than on the unlimed plots, the increases in yields being greatest on the plots which did not receive nitrogen. Potassium gave increased yields on both rotations with little difference between limed and unlimed treatments. Response to nitrogen was greatest on the unlimed plots but was also evident on the limed areas.

Wheat in rotation H showed a response to liming except when nitrogen was applied. There was some response to potassium on the unlimed plots. Nitrogen was most beneficial on the unlimed areas.

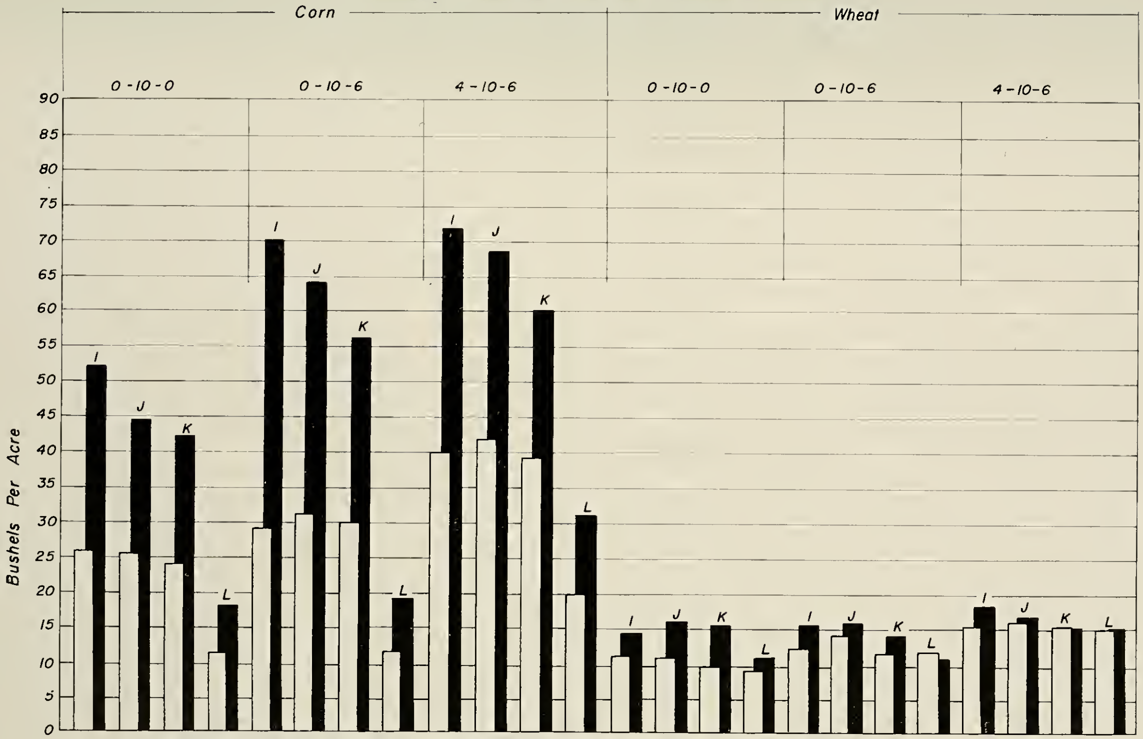
The value of lespedeza (rotation F) as a hay crop for acid soils is evident inasmuch as it produced the highest yields on the unlimed plots with only phosphorus or phosphorus and potassium. However, it usually yielded less than clover and timothy on the limed plots. There appears to be a superiority of barley over wheat as a companion crop for clover-timothy seedings (rotation G vs. rotation H). Increased yield of hay as a result of liming was evident in all rotations and treatments, with the clover and timothy mixture usually showing a greater effect than lespedeza. Increase from potassium applied to the companion crop was evident in all comparisons, being greatest on the limed plots in rotations F and G and on the unlimed plot in rotation H. Nitrogen applied to the small grain had most effect on hay yields on the unlimed plots, probably due to better stand, particularly of grasses, where more nitrogen was available during the early establishment.

TWO-YEAR ROTATIONS

Four rotations were used comparing cover crops with and without lime in two-year rotations. These had been used similarly during the earlier period but the cropping system was changed from corn-soybeans to corn-wheat. Cover crops were changed to fit the new rotations with vetch and sweet clover being used on the unlimed and limed portions respectively of rotation I, lespedeza on rotation J, clover and timothy on rotation K, and no cover crop on rotation L. All cover crops were seeded in the wheat except vetch which was seeded following wheat harvest. The yield results are given in Figure 3.

The kind of cover crop had little effect on corn yield on the unlimed area. Even though growth of the cover crops was poor without lime, there was enough plowed under in all rotations to materially increase

FIGURE 3—Yield of crops in two-year rotations.



Fertilizer was applied at the rate of 250 pounds per acre to corn and 250 pounds per acre to wheat. Analyses used as shown on the bars.

the yield over that obtained in rotation L which had no crop turned under. The effect of turning under green manure crops was much more beneficial on the limed plots. Rotations I, J, K showed increased yields varying from 24.0 to 31.4 bushels of corn per acre above those produced in rotation L. Sweet clover had the greatest effect, followed by lespedeza with clover and timothy showing least effect. This is probably in order of the amount of legume turned under although yields of legumes in the cover crops were not always taken.

Liming increased corn yields in all rotations and with all treatments. The greatest effect was on the plots with cover crops, again emphasizing the value of lime in producing legumes which, in turn, supply nitrogen for the succeeding crop. The addition of potassium to the fertilizer used appears to have influenced the response to liming inasmuch as the increase from lime is greatest on the plots treated with 0-10-6, next on those receiving 4-10-6, and least on those with only superphosphate.

The value of potassium, especially on rotations I, J, and K limed, is very apparent. These are the rotations in which potassium deficiency symptoms were evident before changing the cropping system and fertilizer application. Similar deficiency symptoms were evident during this experiment on the plots without potassium. A small increase from potassium was evident on the unlimed portions of rotations I, J, and K. The lack of response to potassium on rotation L may be explained on the basis that some other deficiency was greater, in this instance probably nitrogen.

Corn responded well to nitrogen on the unlimed portions of rotations I, J, and K, and on both portions of rotation L. On the limed portions of I, J, and K the legumes turned under were apparently supplying almost enough nitrogen to balance the other nutrients that were available.

There was little effect of kind of green manure crop on yield of wheat, but rotations with green manure turned under before the corn yielded more wheat in all but one treatment than the rotations without green manure. Liming resulted in increased yield in all but two plots —rotation L with 0-10-6 fertilizer and rotation K with 4-10-6 fertilizer. Generally, the increase from lime decreased as potassium and nitrogen were added. Increase in yield from potassium was most evident on the unlimed plots. Nitrogen gave larger increases in yield on the unlimed plots and on those without green manure turned under.

MANURE IN ROTATIONS

Crop rotations M, N, and O were continued in order to compare yields when crops were fed to livestock and the manure returned, with those obtained when the grain or hay was harvested and sold and only the residues of stover and straw left on the land. These were altered in that barley was used in place of wheat in rotation M, in place of oats in rotation N, and in place of soybeans in rotation O. The rate of manure application was ten tons per acre plowed under for corn instead of that produced by feeding the crops. This was a lower rate of application than previously used. Different fertilizers were used as indicated in Figure 4. These varied somewhat depending on the rotation and the use of manure or residues.

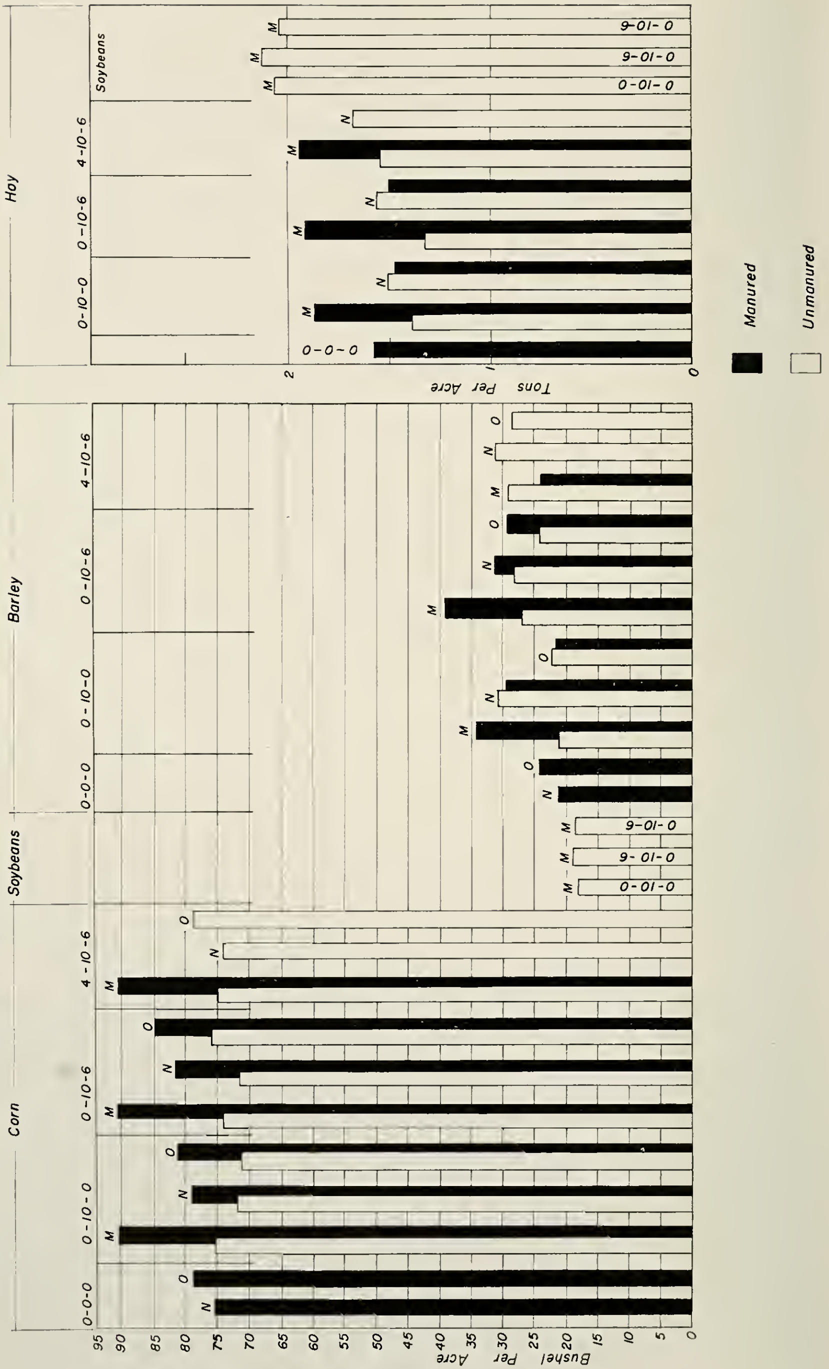
The first difference noted in Figure 4 is the effect of manure on corn yields. This is considerably more than was noted in the results previously reported from these plots. A considerable part of this response from manure was undoubtedly due to the thicker stand of corn which gave a greater utilization of the nutrients available. It should also be noted that this occurred even though the rate of fertilization was only one half as high where manure was applied. Differences in yield from the various rotations under the grain system were variable and probably due to plot variation. Under the livestock system with manure returned, rotation M gave consistently higher yields than either of the other two rotations. Rotation O gave slightly higher yields than rotation N. This may be explained by the larger amounts of manure used (ten tons every two years as compared to ten tons every three years).

The fertilizers on the manured sections of the rotations were all applied to the barley crop. Consequently the effect on corn yield is an effect from fertilizer applied from one to three years before the corn crop. Increases were small, as might be expected, and are probably within experimental error.

Soybeans in rotation M were influenced very little by residual fertilizer. Because soybeans were harvested for grain in one section and hay in the other, it is not possible to compare the grain and livestock systems.

Barley yields were quite variable with low yields resulting either from lack of plant nutrients or loss of part of the crop by lodging. In rotation M on the plots with phosphate or phosphate and potassium, the manure applied to corn about one and one half years before barley planting had enough residual effect to produce a good increase in yield. However, when the manure applications were made in the spring to corn and the barley was planted in the fall after corn as in rotations N and O, there was considerable lodging and loss of crop. As a result there was little positive effect on yield. Phosphate fertilizer had some influence, particularly in rotation N and potassium generally increased yield. Nitrogen gave a small increase on the grain rotation but decreased yield (the result of lodging) on rotation M manured.

FIGURE 4—The effect of manure on crop yields in two-, three-, and four-year rotations.



Manure increased hay yield on rotation M but had no effect on rotation N. Decreased stand because of barley lodging probably offset increased growth in this rotation. The residual effect of the various fertilizers had little effect on hay production.

CONTINUOUS CORN

Continuous corn was grown with rye and vetch and with sweet clover cover crops turned under for green manure. The yields are given in Figure 5. Considerable difficulty was encountered in securing a stand of sweet clover with the result that in the majority of years the comparison was more nearly rye and vetch versus no cover crop.

In all cases the yields were higher where rye and vetch green manure crop was used. The yields improved as potassium and nitrogen fertilizers were added.

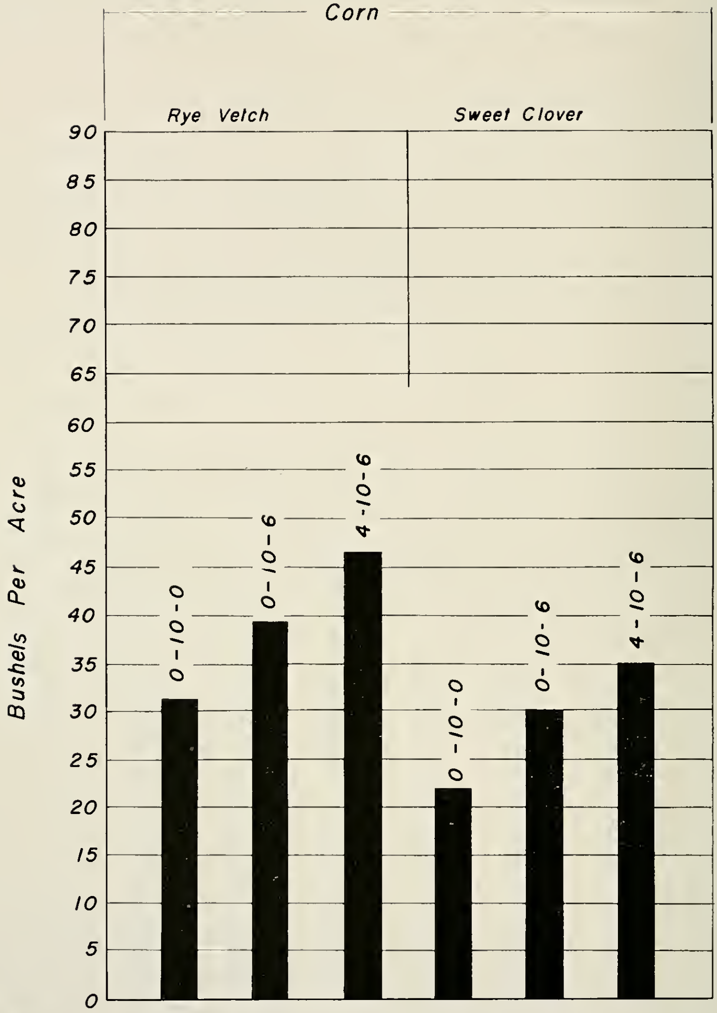
LENGTH OF ROTATION

Previous comparisons have been primarily concerned with different crops or treatments in similar rotations. The length as well as nature of the rotation may be expected to have an influence on yields. In Figure 6 the yields of corn and wheat in selected cropping systems, all limed, are given. These vary primarily in length of rotation and compare (1) continuous corn followed by a rye and vetch cover crop plowed under, rotation W; (2) a two-year rotation of corn, wheat with clover and timothy used as green manure, rotation K; (3) a three-year rotation of corn, wheat, clover and timothy, rotation H; and (4) a four-year rotation of corn, wheat and two years of clover and timothy, rotation C.

Corn yields were lowest with all three fertilizer treatments where corn was grown continuously and highest with the three-year rotation of corn, wheat, clover and timothy. Maintaining clover and timothy for more than one year resulted in decreased corn yields. It should be noted that, although the treatments were the same for corn in all rotations, the average rate of fertilization per year was less in rotation C. Rotation C received 750 pounds per acre in four years, whereas all others received 250 pounds per acre per year. This may be responsible for some of the effect noted but it does not seem to explain all of the decrease as compared to rotation H. The plots with 0-10-6 fertilizer yielded more than those with 0-10-0 in all rotations. Complete fertilizer increased yields of corn over the 0-10-6 fertilizer regardless of length of rotations compared.

Wheat yields were less affected by length of rotation than were corn yields and the effect seemed to be influenced by the fertilizer treatment. The lower yield of the two-year rotation K may have been the result of the lower rate of fertilizer application to the wheat crop. Here, although the

FIGURE 5—Corn yields in a continuous corn cropping system.



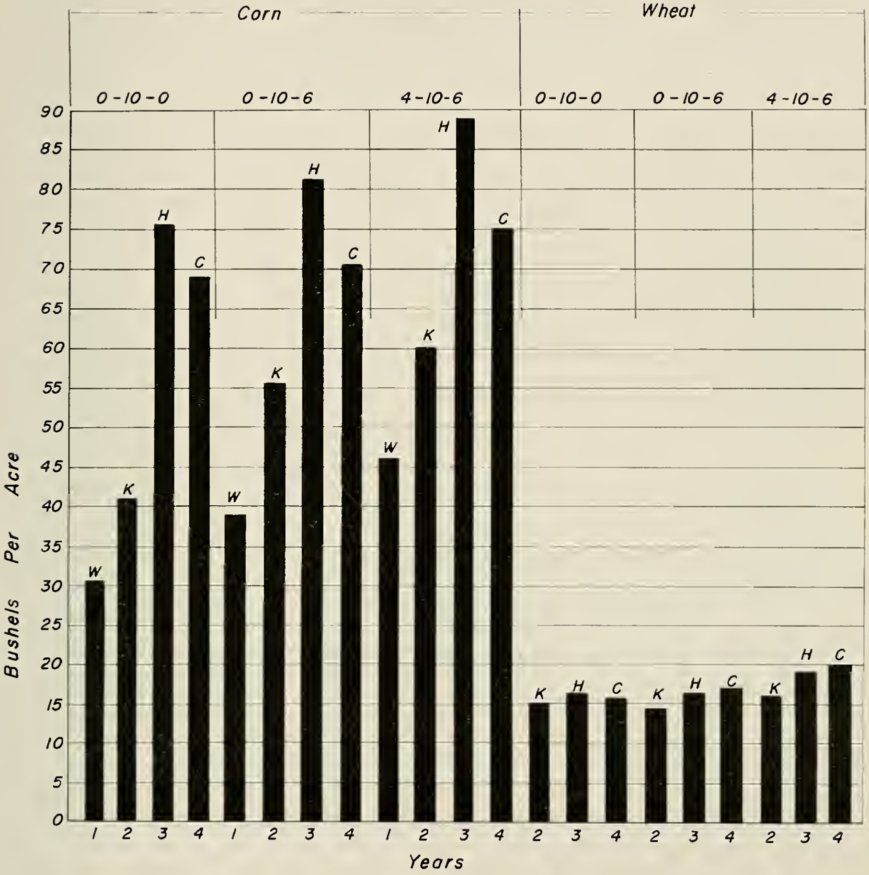
Fertilizer was applied at the rate of 250 pounds per acre of the analysis shown in bars.

average rate of fertilization was the same, only 250 pounds was applied to wheat as compared to 500 pounds in all other rotations. Response to potassium and nitrogen generally increased as the length of rotation increased.

LIMING

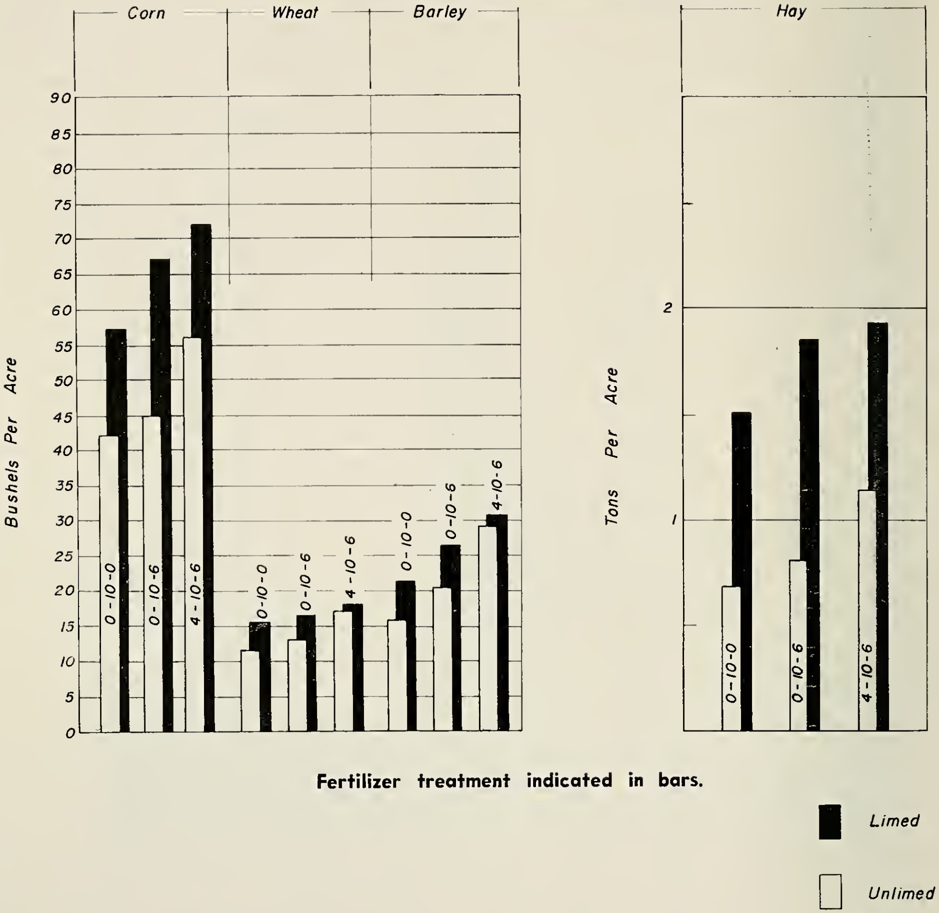
The effect of liming has been noted in the various comparisons made. An over-all summary of this effect is given in Figure 7, in which direct

FIGURE 6—Yield of corn and wheat as affected by length of rotation and fertilizer (all plots limed).



comparisons are made on corn, wheat, barley and clover-timothy hay as an average of all rotations in which limed and unlimed treatments appeared. These show an increase in potato yield where nitrogen was applied and an increase in all other crops regardless of fertilizer treatment. The percentage of increase was greatest in the clover-timothy hay crop, where, without nitrogen, the yield was more than doubled. As previously noted, a considerable part of the increase in yield of crops was undoubtedly the result of better legume growth and more available nitrogen. This is further demonstrated by the fact that, in general, response to lime was least where complete fertilizer was applied. However, as previously noted, higher yields were secured when the soil was maintained near neutrality regardless of fertilizer treatment.

FIGURE 7—Response of crops to lime for rotations.



Experimental Results—1945-52

Following the 1944 cropping season, the cropping systems and treatments were re-evaluated and certain additional changes were made. The response to nitrogen and potassium in certain rotations had been limited by the small amount used. The fertilizer treatments were, therefore, changed so that increased amounts of nitrogen and potassium would be applied in the cropping systems. Changes in fertilizer ratios generally available led to the use of 1-2-1, 1-2-2 and 1-1-1 as standard ratios. The rate of application was continued at 250 pounds per acre per year, but 5-10-5, 5-10-10, or 10-10-10 were used as complete fertilizers instead of the 4-10-6 previously used.

The value of liming was so clearly demonstrated that lime was applied to certain of the unlimed sections of some of the rotations with only a few retained to give further evidence of the effect of lime.

The cropping systems, lime, fertilizer, manure, and cover crop treatments are shown for the various rotations in the figures.

FOUR-YEAR ROTATION—UNMANURED

Rotation A was continued as a four-year rotation of potatoes, corn, wheat, clover and timothy with all of the fertilizer (1,000 pounds per acre) applied to the potatoes, with one section remaining unlimed and the other section maintained above pH 6.0. Because of the good response to nitrogen on the unlimed area, noted earlier, the three treatments on this area were varied only in nitrogen, receiving 0, 50, and 100 pounds of nitrogen per acre on the potatoes. The earlier response to potassium on the limed plots led to the inclusion of a plot with a 5-10-15 fertilizer to determine if additional potassium would continue to increase yields. The yields of crops are given in Figure 8.

Because of variations in nitrogen and potassium treatments, the effect of lime can only be compared with 0-10-10 and 5-10-10 fertilizer treatments. Yields were higher on the limed plots on all four crops with both of these fertilizer treatments. The greatest relative increase was in the yield of clover and timothy hay and the least was in potatoes. The greater yield of legumes in the hay and the larger amount of legume residues plowed under probably accounts for most of the increases in the yield of potatoes, corn and wheat.

The addition of 50 pounds of nitrogen resulted in a good increase in potato yields on both unlimed and limed areas (58.9 and 44.3 bu. per acre, respectively). The additional nitrogen from the 10-10-10 fertilizer gave only a small increase in potato yields. The nitrogen applied to potatoes had little effect on the yield of other crops in the rotation.

The additional potassium applied to the limed section of the plots had little effect on the yield of any of the crops in the rotation.

THREE-YEAR ROTATION

Two three-year rotations were tested at six fertility levels, rotation D—corn, wheat, alfalfa; and rotation E—corn, wheat, clover and timothy. These were designed to compare hay crops of clover and timothy versus alfalfa and their effect on corn and wheat yields. The results are given in Figure 9. These show that yields of corn, wheat and hay were usually higher in the rotations with alfalfa than with clover and timothy. There was a marked response to potassium on corn (5-10-0 vs. 5-10-5) and to nitrogen on wheat (0-10-5 vs. 5-10-5). Hay yields generally were higher on plots to which complete fertilizer was applied at the time of wheat seeding.

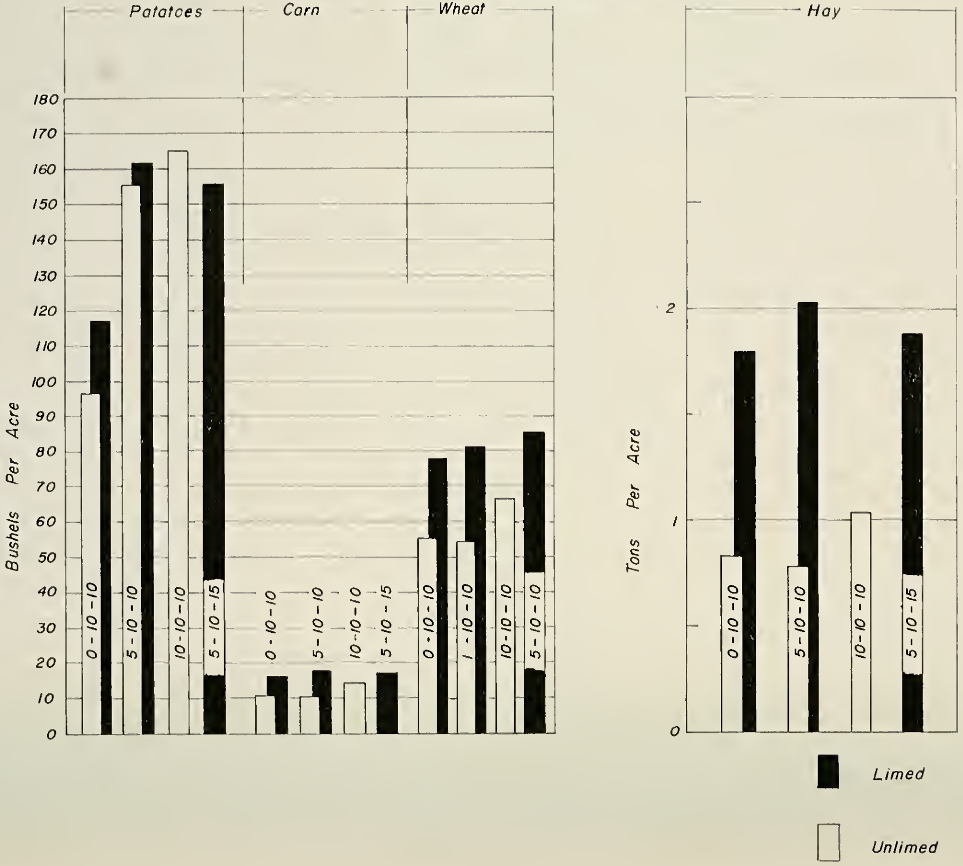
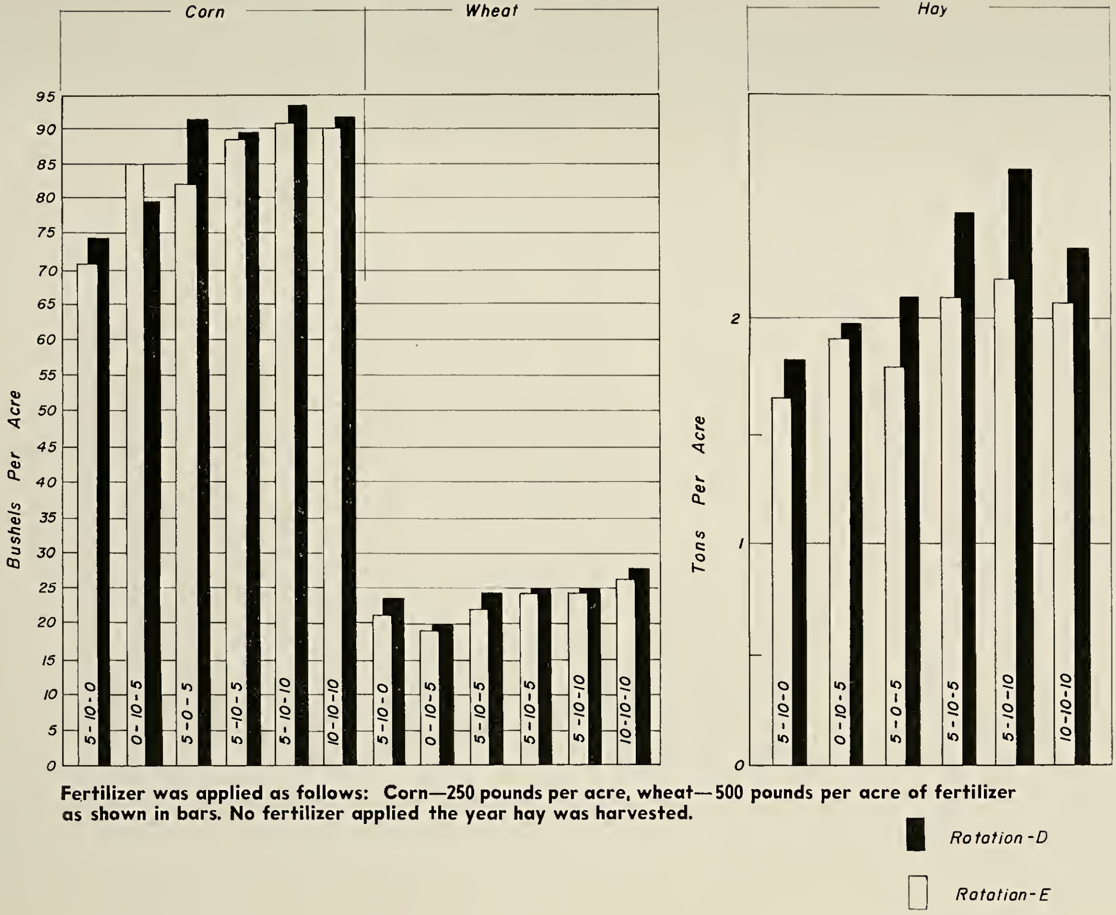


FIGURE 8—Yield of crops in four-year rotation.

FIGURE 9—Yield of crops in three-year rotations.



Fertilizer was applied as follows: Corn—250 pounds per acre, wheat—500 pounds per acre of fertilizer as shown in bars. No fertilizer applied the year hay was harvested.

TWO-YEAR ROTATION

Four two-year rotations of corn and wheat with varying green manure crops were grown on unlimed and limed plots with three different fertilizer treatments. The green manure crops used were (1) rye and vetch on the unlimed portion of rotation I, (2) sweet clover in the limed portion of rotation I, (3) lespedeza on rotation J, and (4) red clover and timothy on rotation K. These were planted in the wheat in the early spring except rye and vetch which were planted after wheat harvest. No crop was seeded for green manure in rotation L. The results are given in Figure 10.

Corn yields were higher on the limed than on the unlimed plots in all comparisons. The increases were usually greatest on the plots which received potassium and a green manure crop. A part of the increase noted in rotation I may have resulted from the use of sweet clover instead of rye and vetch as green manure and the resultant amount of crop turned under. However, the increased yield from liming on rotation L indicates a direct effect of reaction on corn production.

A marked response to potassium is evident on corn in all rotations. This was greatest on the limed plots. On the rotations with green manure (I, J, and K) the increase amounted to over 20 bushels per acre.

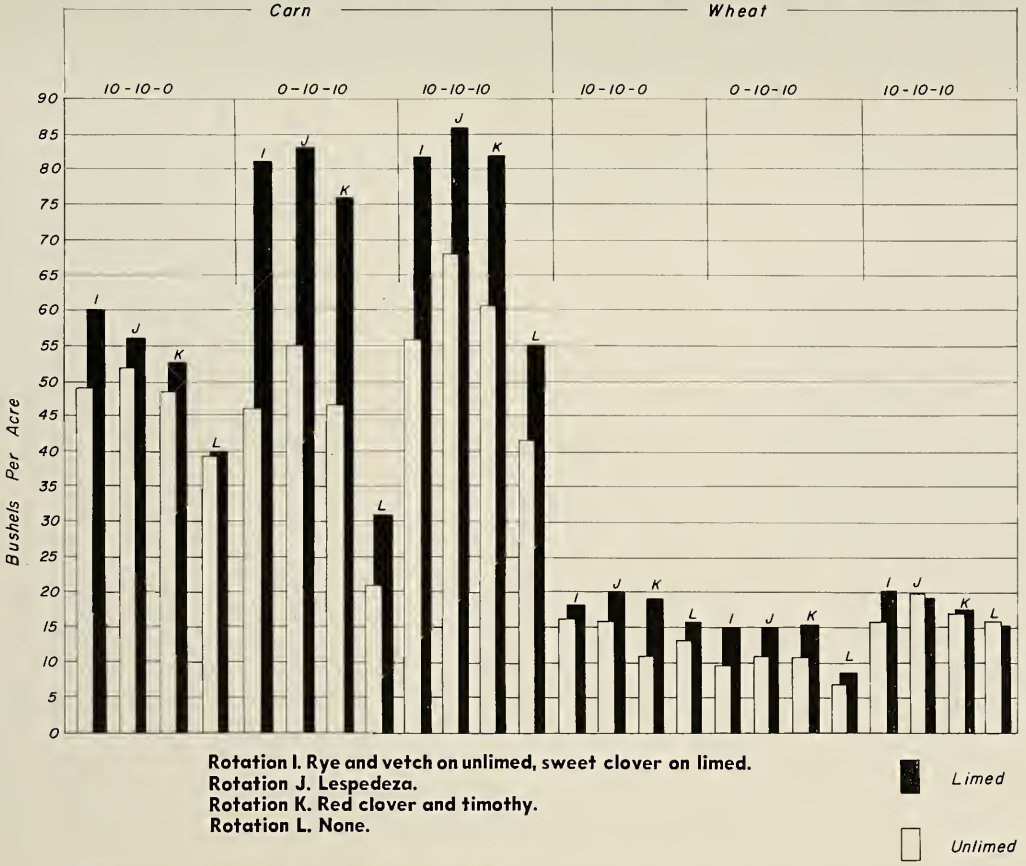
Nitrogen gave increased corn yields in all four rotations, the greatest increase being on those plots which had no green manure (rotation L) and the least on the limed plots which had legumes plowed under.

Wheat yields were usually higher on the limed than on the unlimed plots. This was especially true when either potassium or nitrogen was omitted from the fertilizer. There was little difference in yield due to liming when 250 pounds of 10-10-10 fertilizer was applied. A response to potassium was usually noted on the unlimed plots but potassium had little effect on the limed areas. Response to nitrogen was highest on the unlimed area on all rotations, but the increase on the limed plots indicates that the legume nitrogen was pretty well exhausted before the wheat crop.

MANURE IN ROTATIONS

Three rotations received ten tons of manure plowed under for corn. These were rotation M—corn, soybeans, wheat, clover-timothy; rotation N—corn, wheat, clover-timothy; and rotation O—corn, wheat, with clover-timothy as green manure crop. Fertilizer treatments varied from none to a complete fertilizer. The yields from these rotations are given in Figure 11. Corn yields were relatively high in all rotations, varying from 93.0 to 103.1 bushels per acre. It appears that the combination of manure

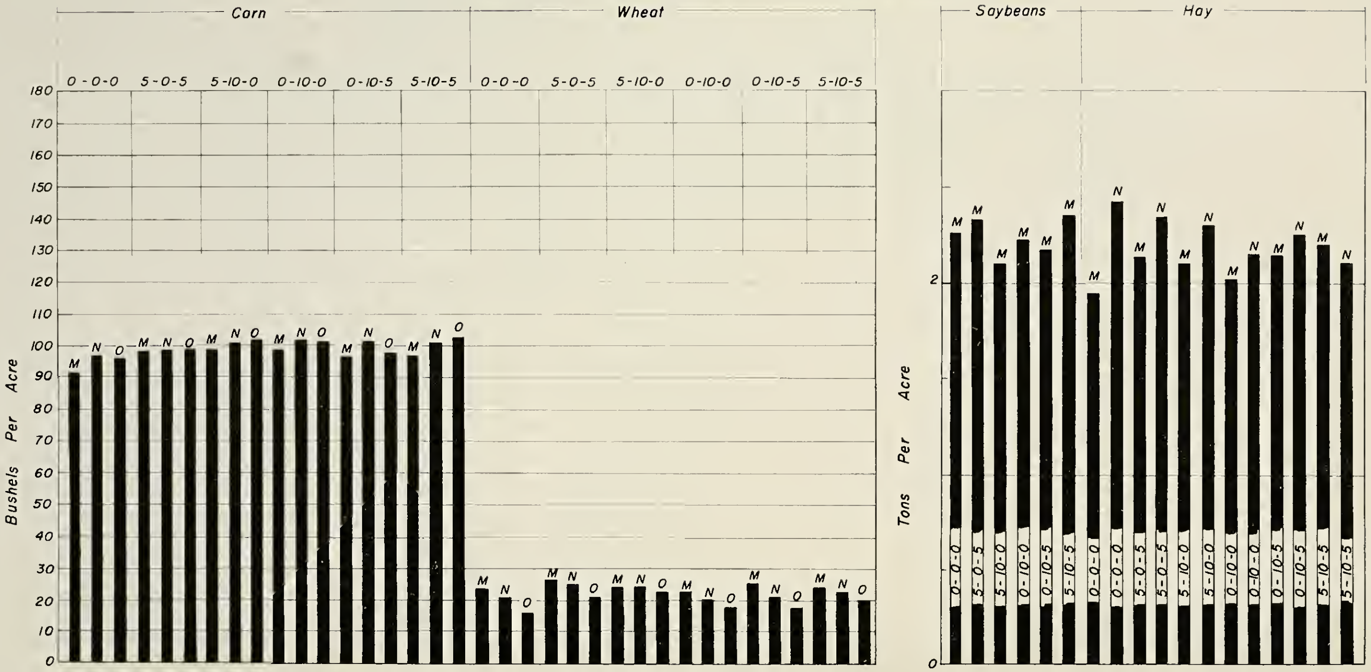
FIGURE 10—Yield of corn and wheat in two-year rotations having different cover crops as follows.



Rotation I. Rye and vetch on unlimed, sweet clover on limed.
Rotation J. Lespedeza.
Rotation K. Red clover and timothy.
Rotation L. None.

Fertilizer was applied to corn and wheat at the rate of 250 pounds per acre of analysis as shown in bars.

FIGURE 11—Yields of crops in rotations with manure.



Fertilizers were applied as follows:

Rotation M. Corn—250 pounds, soybeans—250 pounds and wheat—500 pounds per acre of fertilizer shown in bars.

Rotation N. Corn—250 pounds and wheat—500 pounds per acre of fertilizer as shown in bars.

Rotation O. Corn—250 pounds and wheat—250 pounds per acre of fertilizer as shown in bars.

and clover green manure or sod supplied enough nutrients to produce a good crop of corn. The fertilized plots produced a little more than the unfertilized ones but no particular element (N, P, or K) appeared to be responsible for increased yields.

Wheat yields were generally better on rotations M and N which had a year of clover timothy hay than on rotation O where a cover crop was plowed under before the corn crop. In rotation M the variations in yield did not appear to be associated with any particular fertilizer element. In the other rotations highest yields were associated with the application of nitrogen fertilizer.

Clover and timothy hay yields were usually higher in rotation N than in rotation M. This may reflect the more recent manure treatment. There appeared to be some effect of the potassium fertilizer applied to wheat on hay yields, especially on rotation M.

Soybean yields varied only slightly with fertilizer treatment. Apparently fertility on all plots was sufficient for good growth of soybean hay.

Corn has been grown continuously in rotation W since the rotation experiment was started in 1925. During the period 1945 to 1952, one half of the area was manured each year and the other half had a rye grass-crimson clover cover crop. Three fertilizer treatments were made on each of these sub plots. The results are given in Figure 12.

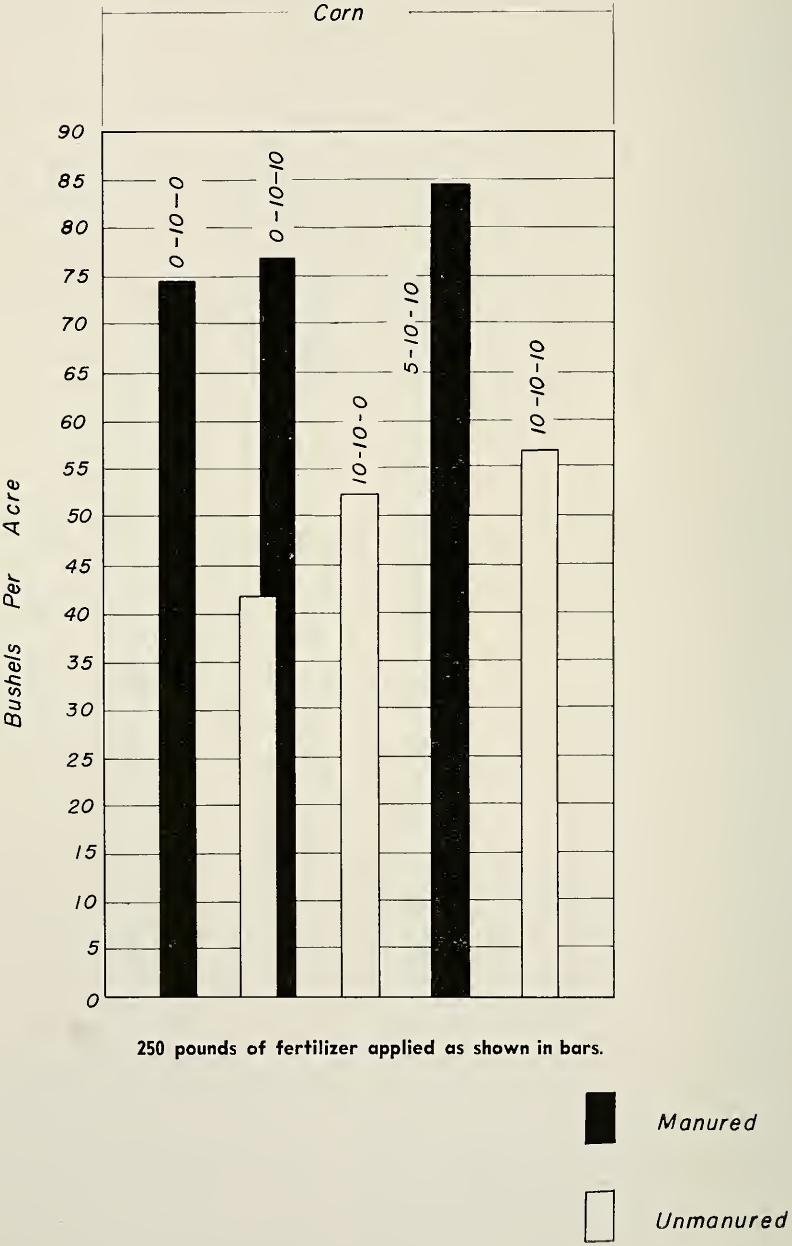
The effect of manuring is quite obvious. In the one direct comparison with 0-10-10 fertilizer, the manured plots yielded 35.3 bushels per acre more corn than the unmanured plots. The complete fertilizer (5-10-10) increased the yield by 9.6 bushels per acre over the plot with phosphorus only on the manured plots. Part of the response seems to be from the nitrogen and part of it from the potassium indicating that ten tons of manure does not supply enough of these elements for corn grown continuously. Response to nitrogen of 14.7 bushels per acre on the unmanured plot indicates that nitrogen was a serious limiting factor. Increased yield from potassium was also evident.

LENGTH OF CROP ROTATION

Comparisons made thus far have been for the most part between rotations of the same length with variation in crops and fertilizer treatment. In the cropping systems used, it is possible to compare yields of corn as influenced by length of rotation. Such comparisons are shown in Table 1 for plots receiving complete fertilizer.

Corn yields increased on unmanured plots as the cropping system was changed from continuous corn to a three-year rotation of corn, wheat, clover and timothy. Continuous corn with cover crop yielded

FIGURE 12—Yield of corn grown continuously.



250 pounds of fertilizer applied as shown in bars.

TABLE 1. EFFECT OF LENGTH OF ROTATION ON CORN YIELDS—1945-52

Cropping System	Unmanured	Manured
	Bu/A	Bu/A
Continuous Corn (Rye Grass-Crimson Clover)*	56.9	84.3
Corn, Wheat (Red Clover-Timothy)*	82.7	103.1
Corn, Wheat, Red Clover-Timothy	90.6	100.3
Corn, Soybeans, Wheat, Red Clover-Timothy	—	96.2

*Cover Crops

All unmanured plots received 250 pounds per acre of 10-10-10 fertilizer, manured plots received 250 pounds per acre of 5-10-5 fertilizer except continuous corn which received 250 pounds per acre of 5-10-10 fertilizer. Manure was applied once in rotation, before plowing for corn, at the rate of ten tons per acre.

25.8 bushels per acre less than corn in the corn-wheat rotation with clover-timothy cover crop. This is probably the result of the much greater cover, especially legume, which was plowed under in this rotation. Maintaining the clover and timothy for a year's hay crop and plowing under the residue instead of plowing the clover and timothy under as a green manure crop increased the yield by 7.9 bushels per acre.

Comparisons of corn on the manured plots show a considerably higher yield in the two-year rotation than in continuous corn. Yields decreased slightly as the length of rotation increased beyond two years. In comparing these rotations, it should be remembered that the longer the rotation the lower the average annual rate of manuring. (The average annual applications per acre were 10 tons, 5 tons, 3⅓ tons, and 2½ tons for the 1-, 2-, 3-, and 4-year rotations, respectively.)

The role of manure in relation to length of rotation is also evident in Table 1. In continuous corn, manure increased yields by 27.4 bushels per acre, in the two-year rotation the increase was 20.4 bushels per acre, and in the three-year rotation the increase was 9.7 bushels per acre. Part of this may have been influenced by the frequency of manuring, but it does emphasize the greater need of manure in short rotations.

Discussion

The results presented here show wide variations in the yields of most crops. These are related to cropping system, liming, and the use of manure and fertilizer. They confirm earlier results but show greater differences resulting from long-time effects of the various practices.

The plots were initially laid out in a manner which would not permit the use of statistical analysis of the results. Consequently, differences must be fairly large and consistent before they can be given much weight. The data presented shows that there are large differences under many circumstances, and in the presentation of results, some of the treatments associated with these differences were pointed out.

The growing of a legume either as a hay crop with residues plowed under or as a green manure crop increased corn yields from 10 to more than 50 bushels per acre depending upon other treatments in the cropping system. The smaller effects were noted where the soil was unlimed and where nitrogen fertilizer was applied, the larger effects were on limed plots without nitrogen. This would indicate that the principal effect appeared to be related to the nitrogen furnished by the legume since growth and nitrogen fixation would be least on acid, unlimed soils and most on the limed soils. Adding nitrogen in the cropping system would have little effect on legume growth but would lessen the difference in nitrogen available for non-legume plants.

The increases in yield associated with increase in length of rotation seemed to be at least in part related to the length of time the legume was growing and the stand which was obtained. The lowest yields of both corn and wheat were obtained in rotation L without nitrogen. There were no legumes in this rotation. Corn yields in the continuous corn plot with a legume planted in the corn at the last cultivation gave somewhat higher yields of corn than were secured in rotation L but less than in the two-year rotation in which a legume was planted in small grain in the spring or after the small grain was removed. In the two-year rotations more legume growth was available to plow under and furnish nitrogen for the grain crops. An additional small increase in yields of corn and wheat seemed to be associated with lengthening the rotation to three years even though the legume was removed as hay.

Liming increased yields of all crops grown. The increase in yield was greatest when legumes were grown in the rotation and was usually less when nitrogen fertilizer was applied. A considerable part of the effect of lime would therefore seem to be associated with the increase in nitrogen availability resulting from increased legume growth and nitrogen fixation. However, there was an effect of lime in rotation L which had no legume. Here the effect could only be attributed to a direct effect of lime on increasing availability of some nutrient or nutrients for corn and wheat or decreasing the amount of some substance, such as aluminum, which might be toxic. The pH of the unlimed plots was lower than the range considered as optimum for the crops grown.

Manure continued to show a marked effect on crop yields. The corn grown immediately after the application of manure gave higher yields than corn under any treatment without manure. The small response to fertilizer treatment on the manured plots, M, N, and O, indicates that at the rate applied, manure furnished most of the available plant nutrients needed on this soil under the conditions of the experiment. These plots have been manured regularly since 1925. The lower yield on manured plots in rotation W, which were manured only during the last eight years, suggests that manure alone for this period was not enough to give maximum yields.

Fertilizer response varied with the effectiveness of other practices in maintaining soil productivity. Response of nitrogen was greatest when legumes were absent or grew poorly because of soil acidity. For example, during the 1945-52 period the response to nitrogen averaged 12.7 and 7.4 bushels for corn and wheat respectively on the unlimed plots of rotations I, J, and K as compared to 3.8 and 4.0 bushels for corn and wheat on the limed portions of these same rotations. Without legumes on rotation L, the increases related to nitrogen were 20.0 and 8.3 bushels for corn and wheat on the unlimed portion and 22.8 and 7.0 bushels for corn and wheat on the limed portion.

The rate of nitrogen application was 25 pounds per acre per year, so the increases were about one bushel of corn for two pounds of nitrogen on the unlimed areas with legumes and about one bushel of corn for one and one-fourth pounds of nitrogen on the plots without a legume. These values indicate a critical nitrogen deficiency. The increases for wheat were about one bushel for each three and one-half pounds of nitrogen without legumes or on the acid soils where legumes grew poorly. With good growth of legumes on the limed plots, the increases were only one bushel of corn or wheat for about six pounds of nitrogen; indicating a much lower nitrogen deficiency and lower utilization of applied nitrogen. The relatively greater response to wheat than corn in this case was undoubtedly the result of much of the nitrogen from the legumes being available and utilized by the corn crop immediately following the plowing under of the legumes and a lesser carry-over the next year for the wheat crop. Response to nitrogen was generally low on the manured plots.

As previously indicated, potassium deficiency was noted on some of the plots soon after the experiment started. Response to potash was greatest on the plots which had been limed and on which legumes furnished enough nitrogen for good yields. There was little response to potassium fertilizer on the manured plots. Apparently the manure supplied the potassium necessary for the crops grown.

An attempt was made to measure changes in soil structure associated with the various cropping systems and treatments but the variations in texture were so great that they obscured any possible structural changes. In no case was there any evidence that soil structure had changed sufficiently to have any effect on the yields of the crops grown.

In the discussion of results, more emphasis has been placed on corn than on any other crop. This was done for two reasons: (1) corn was the only crop grown in all rotations, and (2) it appeared to be more affected by treatment than the other crops. Corn yields in general reflected the effect of treatment more than did the yields of any other crop.

Wheat and other small grain yields were generally lower than desired. Other experimental results indicate that nitrogen applied in the spring on this soil would have had more effect than the fall application.

Hay yields reflected the management as well as fertility. Clover and timothy were cut for hay only once during the season and the second growth was left on the land. This resulted in decreased measured hay yields but probably helped keep corn yields at a higher level than would have been the case if all the hay had been removed. However, in most cases, the re-growth was rather poor. Alfalfa was cut two or three times each year in rotation D but average yields are low because some years with virtual crop failures are included in the average. The highest alfalfa yield on a single plot in the best year was slightly over 4.0 tons per acre.

Potato yields were low because of inadequate control of insects and diseases. In spite of this, there were marked effects from fertilizer treatment.

APPENDIX

Table A. Yield of Crops in Various Rotations (1937-1944)

Cropping System	Rate	Fertilizer Analysis					
		Unlimed			Limed		
		0-10-0	0-10-6	4-10-6	0-10-0	0-10-6	4-10-6
ROTATION A							
Potatoes (Bu)	750	63.2	97.9	132.4	77.3	111.2	107.5
Corn (Bu)	250	70.2	73.0	82.5	77.4	83.0	87.1
Wheat (Bu)	500	14.0	15.4	20.9	16.8	19.4	22.6
Clover-Timothy (Tons)		0.64	0.63	0.98	1.49	1.73	1.80
ROTATION C							
Corn (Bu)	250	41.3	40.8	55.6	68.9	71.2	75.0
Wheat (Bu)	500	13.0	14.5	18.0	16.8	18.2	20.9
Clover-Timothy (Tons)		0.70	0.55	0.87	1.32	1.67	1.64
Timothy (Tons)		0.94	1.23	1.37	0.67	0.75	0.89
ROTATION F							
Corn (Bu)	250	58.8	61.9	70.5	65.4	75.5	81.7
Barley (Bu)	500	16.8	20.6	27.9	21.2	25.0	30.3
Lespedeza (Tons)		1.14	1.21	1.31	1.58	1.80	1.76
ROTATION G							
Corn (Bu)	250	61.8	70.0	76.4	74.3	79.0	86.7
Barley (Bu)	500	15.9	21.0	30.0	21.6	28.8	31.3
Clover-Timothy (Tons)		0.93	1.01	1.48	1.82	2.00	1.92
ROTATION H							
Corn (Bu)	250	59.0	61.9	75.7	76.8	83.6	88.2
Wheat (Bu)	500	12.9	14.4	19.1	17.0	17.0	18.1
Clover-Timothy (Tons)		0.66	0.87	1.26	1.69	1.77	1.92
ROTATION I							
Corn (Bu)	250	26.7	29.3	40.4	52.5	70.4	72.2
Wheat (Bu)	250	12.4	13.0	16.1	14.2	16.4	18.2
ROTATION J							
Corn (Bu)	250	26.0	32.5	42.6	44.0	64.5	68.8
Wheat (Bu)	250	12.8	14.0	16.7	16.2	16.5	17.9
ROTATION K							
Corn (Bu)	250	24.2	30.1	39.9	42.7	56.9	60.1
Wheat (Bu)	250	10.2	12.3	16.6	15.6	14.2	16.1
ROTATION L							
Corn (Bu)	250	12.8	12.1	20.3	18.7	19.0	31.9
Wheat (Bu)	250	9.7	12.3	15.2	11.2	11.5	15.7
ROTATION W		Rye Vetch Cover			Sweet Clover Cover		
Corn (Bu)	250	31.0	38.6	47.4	22.6	30.0	35.4

TABLE A.—CONTINUED

CROPPING SYSTEM	RATE	ANALYSIS					
		UNMANURED			MANURED		
		0-10-0	0-10-6	4-10-6	0-10-0	0-10-6	4-10-6
ROTATION M							
Corn (Bu)	250	77.5	74.5	75.4			
Soybeans (Bu)	250	18.4	19.4	18.9			
Barley (Bu)	500	21.5	27.6	29.6			
Clover-Timothy (Tons)		1.41	1.38	1.38			
ROTATION M							
Corn (Bu)					92.9	92.2	91.4
Soybeans (Tons)					2.06	2.08	2.04
Barley (Bu)	500				34.4	39.5	24.9
Clover-Timothy (Tons)					1.81	1.83	1.89

CROPPING SYSTEM	RATE	ANALYSIS					
		UNMANURED			MANURED		
		0-10-0	0-10-6	4-10-6	0-0-0	0-10-0	0-10-6
ROTATION N							
Corn (Bu)	250	73.8	72.1	74.7			
Barley (Bu)	500	30.9	28.1	32.0			
Clover-Timothy (Tons)		1.50	1.38	1.38			
ROTATION N							
Corn (Bu)					76.9	79.9	83.1
Barley (Bu)	375				24.3	29.9	31.6
Clover-Timothy (Tons)					1.58	1.81	1.83

CROPPING SYSTEM	RATE	FERTILIZER ANALYSIS					
		UNMANURED			MANURED		
		0-10-0	0-10-6	4-10-6	0-0-0	0-10-0	0-10-6
ROTATION O							
Corn (Bu)	250	72.1	76.0	78.4			
Barley (Bu)	250	23.9	24.7	28.7			
ROTATION O							
Corn (Bu)					79.0	82.9	85.4
Barley (Bu)	250				21.7	23.5	29.8

Table B. Yield of Crops in Various Rotations (1945-1952)

Cropping System	Rate	Fertilizer Analysis					
		Unlimed			Limed		
		0-10-10	5-10-10	10-10-10	0-10-10	5-10-10	5-10-15
ROTATION A							
Potatoes (Bu)	1000	97.1	156.0	163.8	116.9	161.2	155.5
Corn (Bu)		57.9	56.0	67.2	78.0	81.7	85.2
Wheat (Bu)		10.3	10.2	12.9	16.3	18.1	17.2
Clover-Timothy (Tons)		0.84	0.81	1.07	1.80	2.05	1.85

Cropping System	Rate	Fertilizer Analysis					
		Unlimed			Limed		
		10-10-0	0-10-10	10-10-10	10-10-0	0-10-10	10-10-10
ROTATION I*							
Corn (Bu)	250	47.9	46.1	57.7	60.5	81.3	82.6
Wheat (Bu)	250	16.7	9.5	16.8	18.9	15.0	20.1
ROTATION J**							
Corn (Bu)	250	52.8	55.6	68.1	56.7	83.0	86.7
Wheat (Bu)	250	16.4	11.3	20.0	21.4	15.0	19.9
ROTATION K†							
Corn (Bu)	250	48.8	47.5	61.6	53.0	76.3	82.7
Wheat (Bu)	250	12.3	10.9	17.2	19.9	15.5	17.6
ROTATION L							
Corn (Bu)	250	38.4	22.2	42.2	40.1	32.3	55.1
Wheat (Bu)	250	13.9	7.9	16.2	15.9	8.8	15.8

Cropping System	Rate	Fertilizer Analysis					
		All Plots Limed					
		5-10-0	0-10-5	5-0-5	5-10-5	5-10-10	10-10-10
ROTATION D							
Corn (Bu)	250	74.3	79.4	91.0	89.8	93.5	91.8
Wheat (Bu)	500	23.8	19.6	24.1	25.1	25.4	27.9
Alfalfa (Tons)		1.78	1.99	2.11	2.49	2.61	2.37
ROTATION E							
Corn (Bu)	250	71.7	85.3	84.9	88.5	91.6	90.6
Wheat (Bu)	500	21.6	18.9	22.0	24.2	24.4	26.1
Clover-Timothy (Tons)		1.65	1.88	1.87	2.11	2.20	2.03

*Vetch used as cover and green manure crop on unlimed plots, sweet clover on limed plots.

**Lespedeza used as cover and green manure crop.

†Red clover and timothy used as cover and green manure crop.

Table B.—Continued

Cropping System	Rate	Fertilizer Analysis					
		All Plots Limed and Manured					
		0-0-0	5-0-5	5-10-0	0-10-0	0-10-5	5-10-5
ROTATION M							
Corn (Bu)	250	91.8	98.2	99.1	99.2	96.0	96.2
Soybeans (Tons)	250	2.25	2.31	2.17	2.23	2.20	2.28
Wheat (Bu)	500	24.4	26.5	24.8	22.3	23.9	23.9
Clover-Timothy (Tons)		1.98	2.19	2.13	2.01	2.16	2.27
ROTATION N							
Corn (Bu)	250	97.3	98.2	100.9	100.4	100.3	100.3
Wheat (Bu)	500	21.6	25.0	24.2	20.7	21.3	22.4
Clover-Timothy (Tons)		2.36	2.38	2.37	2.16	2.31	2.13
ROTATION O							
Corn (Bu)	250	95.9	99.9	101.3	100.3	98.1	103.1
Wheat (Bu)	250	17.6	21.3	22.2	18.5	18.5	20.8

Cropping System	Rate	Analysis					
		Manured			Unmanured		
		0-10-0	0-10-10	5-10-10	10-10-0	0-10-10	10-10-10
ROTATION W							
Corn (Bu)	250	74.7	77.5	84.3	52.9	42.2	56.9